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A "NEW LOOK" IN RELIABILITY -
F-18 OPERATIONAL MISSION ENVIRONMENT

STUDY PROJECT REPORT
PMC 77-1

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A "NEW LOOK" IN RELIABILITY -
F-18 OPERATIONAL MISSION ENVIRONMENT

Individual Study Program

Study Project Report

Prepared as a Formal Report

Defense Systems Management College

Program Management Course

Class 77-1

by

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May 1977

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A"NEW LOOK" IN RELIABILITY - F-18 OPERATIONAL MISSION ENVIRONMENT		5. TYPE OF REPORT & PERIOD COVERED Study Project Report 77-1
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) DOUGLAS P. DUNBAR, JR.,		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS DEFENSE SYSTEMS MANAGEMENT COLLEGE FT. BELVOIR, VA 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS DEFENSE SYSTEMS MANAGEMENT COLLEGE FT. BELVOIR, VA 22060		12. REPORT DATE 77-1
		13. NUMBER OF PAGES 37
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

UNLIMITED

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SEE ATTACHED SHEET

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

SEE ATTACHED SHEET

DEFENSE SYSTEMS MANAGEMENT COLLEGE

STUDY TITLE: A "NEW LOOK" IN RELIABILITY - F-18 OPERATIONAL MISSION ENVIRONMENT

STUDY PROJECT GOALS:

To explain, analyze and evaluate the F-18 operational mission environment (OME) concept of design and test requirements with respect to system reliability improvement and life cycle cost savings.

STUDY REPORT ABSTRACT

This study project examines the F-18 program's development of an expected operational mission environment (OME) of the airplane to tailor existing specifications for design and test requirements of systems and equipment. Based on F-18 contractor studies and reports plus interviews of contractor and Navy Project Management Office personnel, discussion is presented treating establishment of mission profiles/environments, expected reliability improvements and life cycle cost savings. Study results indicate that use of the OME concept will significantly increase F-18 operational reliability as compared to existing carrier-based aircraft. Analysis also indicates that a "front end" investment cost of approximately three million dollars for OME design and test of selected mission-critical equipment will result in a savings of over 100 million dollars in operating and support costs through manpower, spares and rework reductions.

Recommendations include establishment of a requirement for, and standard methodology of developing mission profiles early in the acquisition cycle of future systems. The expected operational environment derived from these profiles should then form the baseline for design and test requirements of systems and equipment.

SUBJECT DESCRIPTORS: Reliability, Reliability Testing, Mission Profiles, Environmental Testing, Life Cycle Costs

NAME, RANK, SERVICE	CLASS	DATE
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EXECUTIVE SUMMARY

A key factor in the success of the F-18 Naval Strike Fighter will be attainment of reliability levels significantly higher than current carrier-based aircraft. Reliability criteria and life cycle cost considerations have been established as equal in importance with performance in the design phase of this weapon system. Traditional design and test requirements have often been found to be inadequate in representing fleet operating stresses imposed on aircraft and equipment. As a result, the operational environment contributes to failure modes that were not considered during design, nor discovered and corrected during demonstration and tests. To solve this problem, the F-18 Program Office and prime contractor have developed realistic mission profiles to help define the expected operational mission environment (OME) of the airplane. A comprehensive analysis of operational and environmental conditions was used to tailor existing specifications for design and test requirements of systems and equipment. The use of this innovative concept should greatly increase the operational reliability of the F-18 airplane and significantly reduce life cycle costs. Analysis indicates that a "front end" investment cost of approximately three million dollars for OME design and test of selected mission-critical equipment should save over 100 million dollars in operating and support costs through manpower, spares and equipment rework reductions.

Coupled with the improvements in design and test methods, the F-18 prime contract specifies stringent reliability requirements that must be demonstrated during various phases of development. An award payment

plan based on reliability, maintainability and life cycle cost considerations was established to incentivize the contractor in achieving increased systems effectiveness. The overall approach taken to increasing F-18 reliability early in the acquisition cycle serves to demonstrate the Navy's commitment to improving operational readiness and reducing operating and support costs of new fleet weapon systems.

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SECTION I

INTRODUCTION

Background

The US Navy has for many years been facing the serious challenge of providing operating forces with reliable weapon systems and equipment. Reliability shortfalls in the fleet are seriously degrading combat effectiveness, and at the same time are driving support costs to new highs. While the less-than-desired operational readiness of fleet weapon systems is the primary concern of operational commanders, increased ownership costs coupled with a severe demand on the logistics pipeline continue to rise faster than the Navy's budget or supply system can effectively handle (20:13)[1]. The total effect is that the Navy is not getting the maximum benefit from each scarce dollar it receives.

To reverse the trend described above, the Navy must stress increased reliability of new weapon systems to improve mission effectiveness, and at the same time reduce support costs. The logical point to start this emphasis is in the early phases of the procurement cycle. Reliability must be designed into a weapon system and adequate tests must be performed to demonstrate and evaluate the design. While this concept has been known and exposed for some time in Military Standards and Specifications, the fact is that systems in the fleet have not experienced overall tangible improvements in reliability. Although systems and equipment

[1]This notation will be used throughout the report for sources of major reference. The first number is the source listed in the bibliography. The second number is the page in the reference.

may have succeeded in meeting specified reliability goals in the laboratory, those same systems have not performed well in the fleet environment (7:24).

Present design and demonstration tests are generally structured around existing Military Specifications modified by the government and contractors with limited knowledge of the performance and environmental capabilities actually expected of the system. The key to improved weapon system reliability in the fleet lies in new initiatives in design and test requirements during development. Expected operational and environmental conditions derived from realistic mission profiles must be established as one of the first steps in the acquisition cycle. This process is being utilized in the development of the F-18 Naval Strike Fighter. The expected operational mission environment (OME) of the airplane has been established and is being utilized as the baseline for system design and test requirements. This new OME concept is a joint Navy/contractor effort that should substantially improve fleet reliability and readiness, and at the same time significantly reduce life cycle costs.

Early in the conceptual phase of the development of the Naval Air Combat Fighter (NACF), industry was solicited for "state of the art reliability technology" of the 1980's. Contractor responses to this Presolicitation Notice (PSN) of 15 June 1974 and results of the Chief of Naval Operations (CNO) Fighter Study IV, April 1974, formed the quantitative reliability requirements for the proposed Naval Strike Fighter. Reliability levels necessary to meet the threat and operational scenario were specified in the Operational Requirements (OR) and the Decision Coordinating Paper (DCP) for this proposed system. These requirements, along with a framework

demonstration and test program were presented in the Reliability Specifications of the Request for Quotations (RFQ) distributed to industry (13:7). Included in the RFQ was the requirement for a study to completely define the operational environment of the airplane weapon system and each element that comprised the system in order to realistically design and evaluate specified reliability requirements. Subsequent to this conceptual effort, Congress directed the Navy to evaluate the two US Air Force Lightweight Fighter Prototypes - the General Dynamics YF-16 and Northrop YF-17 - to satisfy Naval Air Combat Fighter requirements. The logic was that since both aircraft had completed a validation phase "fly-off," technical risks and overall program costs to the Navy could be reduced. The YF-16 and YF-17 contractors each teamed with contractors who had successful experience in designing carrier-based aircraft, to develop design proposals that met Navy requirements. Major design modifications to the prototypes concentrated on meeting carrier suitability requirements. These included adding catapult and arresting capability, redesign of the landing gear, strengthening the fuselage to take carrier loads and aerodynamic changes to allow a slow, flat landing approach required in the carrier environment. Navy range and performance needs dictated additional fuel and all-weather avionics which increased the size and weight of the airplane as compared to the prototype. The McDonnell/Northrop team's modified YF-17 design was selected by the Navy as the design that best met service needs. The airplane was redesignated the F-18 Naval Strike Fighter and McDonnell Aircraft Company (MCAIR) was awarded the prime contract for development. The system is currently in Full Scale Engineering Development, and first flight of the airplane is scheduled in mid-1978.

Purpose

The purpose of this study is to examine the F-18 Naval Strike Fighter operational mission environment (OME) concept of design and test requirements. Specifically, this study presents an overview of the F-18 OME concept, development of the airplane's mission profiles and environment, and evaluates potential improvements in fleet reliability and life cycle cost savings.

Scope

This study focuses on the concepts of the F-18 OME, mission profiles/mission environment, and reliability/life cycle cost implications from a management point of view. Specific or detailed technical considerations and procedures involved in the selection of appropriate sustained loads, vibration, thermal and other climatic design and test environments are beyond the scope of this study. This research effort was invaluable from an educational standpoint as well as in preparation for a forthcoming tour within the Naval Air Systems Command F-18 program organization. It is hoped that this study will be beneficial to others in the field of acquisition management and help to improve the operational reliability of defense weapon systems.

SECTION II

OPERATIONAL MISSION ENVIRONMENT

General

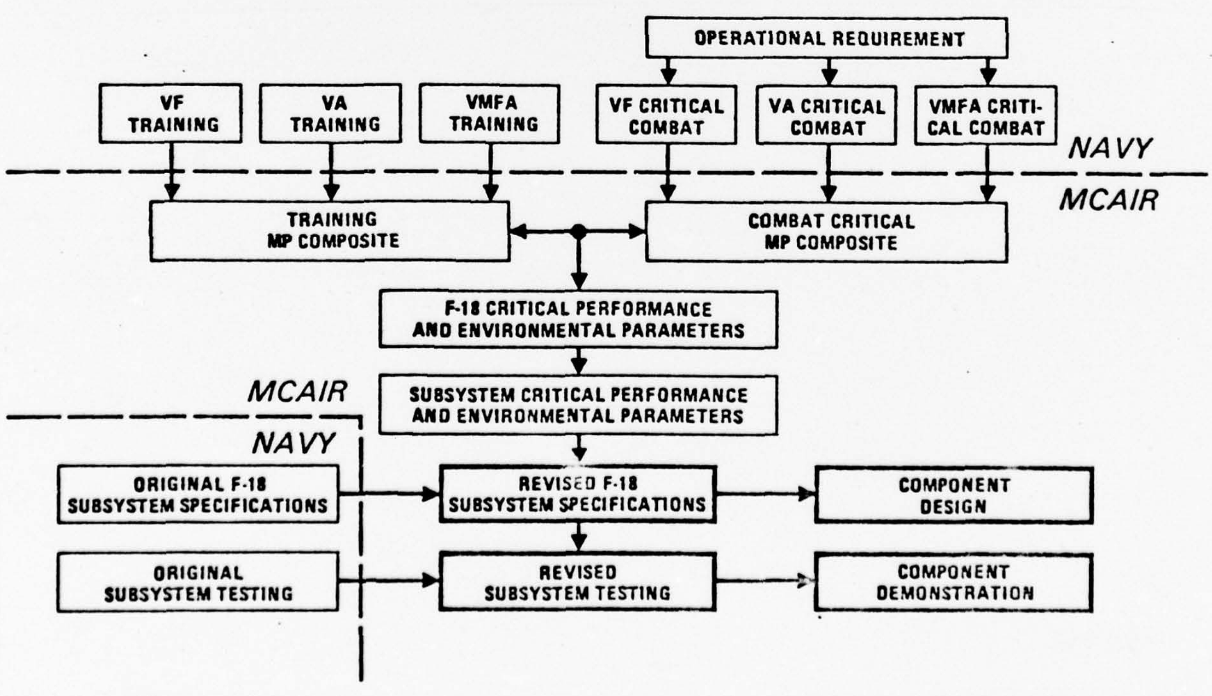
Current design and test requirements have often been found to be inadequate in representing fleet operating stresses imposed on aircraft and equipment. As a result, the operational environment is contributing to failure modes that were not considered during design, nor discovered and corrected during demonstrations and tests (7:25). A significant improvement in the reliability of the F-18, as compared to existing carrier-based airplanes, is one of the highest program objectives (2). High reliability, starting in the design phase, is an equal partner with performance and cost of the system. The effort to achieve design reliability is based on a set of acquisition policies that utilize sound system engineering practices and disciplined program management techniques.

The F-18 OME is composed of all environmental factors to which the airplane and subsystems will be exposed during its operational lifetime. This encompasses typical operational mission profiles for training and combat, critical flight conditions in the F-18 flight envelope, occasional transient excursions beyond normal performance limits of the airplane and pilot, and ground handling and storage environmental conditions (8:1). The OME forms the basis for establishing expected flight loads, vibration, temperature, altitude, humidity, acoustics, salt and dust design and test requirements. Critical design points from the OME become design-to requirements for all systems and equipment. These design-to requirements are contained in the Navy/MCAIR prime specifications

and are allocated from the contractor to subcontractors through equipment procurement specifications. Thus, design and test conditions tailored to the expected environment of individual equipments can be derived, and testing to mundane conditions not significantly affecting equipment failures can be eliminated (8:2).

Development of this approach has required extensive coordination between the contractor and the Navy (1). Figure 1 indicates the approach utilized (9:4). Mission mixes are presented for Navy fighter (VF), Navy attack (VA), and Marine fighter/attack (VMFA) squadrons. Fighter and attack combat critical missions were selected satisfying the Operational Requirement established for the designs, i.e., primary fighter role - Strike Escort, and primary attack role - Interdiction.

FIGURE 1 - F-18 MISSION PROFILES (MP) IN DESIGN AND TEST



F-18 Mission Profiles

A mission profile is a detailed technical description of the various operations, duty cycles, environmental conditions and other factors which define the expected operational use of a deployed system in the fleet (16:4). This information is indispensible to the satisfactory design and test of the system at the contractor's plant. It provides the baseline against which system and equipment reliability and performance can be measured. Military procurement specifications rarely include an adequate mission profile, nor are contractors routinely required to develop one. This deficiency is due to the absence of military standard methodology for mission profile development and use (16:4). The result of this omission is serious reliability shortfalls upon deployment, when the system begins to experience for the first time the service use for which it was intended.

Since a key factor in the success of the F-18 will be attainment of reliability much higher than current aircraft, strong emphasis was placed on the derivation of realistic operational mission profiles. These profiles will then define the environment within which the system will be designed, tested, and expected to perform.

Definitions of the missions for the F-18 was the first step in this process. Typical missions for the Navy fighter and attack models of the airplane include (9:6):

- Fighter Escort
- Barrier Combat Air Patrol (CAP)
- Deck Launch Intercept (DLI)
- Air Combat Training
- Interdiction
- Close Air Support (CAS)
- Low Level Navigation/Strike
- Carrier Qualifications
- Surface, Subsurface Search
- Ferry
- Familiarization/Instrument Training

Critical combat missions were based on the Operational Requirement; training missions were developed from squadron surveys, training syllabus requirements for similar aircraft and pilot experience data. A frequency of occurrence for each mission, as well as ship/shore sortie and combat/training mission ratios were also established. These were based on past experience and the intended role of the F-18 (9:3). Individual missions consist of up to 15 segments (climb, cruise, combat, air refueling, descent, etc.) which define the profile to be flown. Performance parameters such as Mach, altitude, distance, fuel and time were calculated for each mission segment. These parameters, as well as mission segments, were supplied by the Naval Air Systems Command. The resulting mission profiles cover a wide spectrum of airspeed, altitude, weapon loadings and maneuver conditions, and represent the manner in which the airplane is expected to be employed during its life cycle.

To establish design and test conditions for F-18 equipment, a single mission containing the total performance spectrum was required. This composite mission profile, shown in Figure 2 (9:9), was developed by weighting the performance parameters of each individual mission by the frequency of mission occurrence. Wide variances from the average

FIGURE 2
F-18 COMPOSITE MISSION FOR NAVY AND MARINE SQUADRONS
Total Flight Time = 112.6 Min

Mission Segment	Time Minutes	Mach Number				Altitude - Feet			
		Average		Range		Average		Range	
Climb Out	2.8	Start	End	Start	End	Start	End	Start	End
		0.70	0.76	0.2 → 0.9	0.22 → 0.90	SL	24,545	SL	600 → 42K
		Rate-Of-Climb-fpm							
		11,403		706 → 50,000					
Cruise Out	26.0	0.65		0.22 → 0.81		23,204		SL → 40,400	
Loiter	16.7	0.54		0.38 → 0.72		15,833		12,500 → 25,000	
Dash Out	3.6	0.92		0.71 → 1.40		18,109		SL → 70,000	
Accelerate	0.2	Accel From 0.6 To 0.98		From → To (0.3–0.9) → (0.7–1.4)		13,545		SL → 40,000	
Combat	8.1	0.94		0.20 → 1.30		13,086		SL → 30,000	
Dash Back	3.6	0.91		0.71 → 1.10		19,190		SL → 36,089	
Climb Back	0.7	Start	End	Start	End	Start	End	Start	End
		0.78	0.82	0.72 → 0.85	0.78 → 0.87	13,815	28,054	SL → 36K	15 K → 45.6 K
		Rate-Of-Climb-fpm							
		12,392		3,147 → 16,667					
Cruise Back	12.6	0.61		0.22 → 0.81		20,838		600 → 46,400	
Loiter	30.6	0.35		0.32 → 0.42		12,200		5K → 20,000	
Descend	7.7	Start	End	Start	End	Start	End	Start	End
		0.59	0.33	0.22 → 0.81	0.22 → 0.80	22.5 K	2.5 K	5K → 45.6K	SL
		Rate-Of-Descent - fpm							
		3,582		194 → 4,048					
Land	0.5	–		–		–		–	

flight profile are included and serve to define the probable range of expected performance parameters. Figure 3 (9:12) translates the composite mission times into the 6,000 flight hours service life of the airplane, and also adds the ground operation events associated with the mission.

FIGURE 3
F-18 6000 FLIGHT HOUR SERVICE LIFE
BY MISSION SEGMENT

MISSION SEGMENT		TIME/SEGMENT (MIN)	TOTAL TIME (HR)
Start Up and Idle	Ground	19.67	1047.7
Taxi		1.86	99.1
Take Off		0.55	29.3
Climb Out	Flight	2.83	150.7
Cruise Out		25.98	1384.4
Loiter		16.73	891.2
Dash Out		3.58	190.7
Accelerate		0.24	12.3
Combat/Attack		8.11	431.9
Dash Back		3.63	193.4
Climb Back		0.66	35.2
Cruise Back		12.55	668.5
Descent		7.75	412.8
Loiter		30.58	1628.9
Landing	Ground	0.47	25.0
Taxi		8.75	466.1
Total Ground Time		31.30	1667.2
Total Flight Time		112.64	6000.0
Total Mission Time		143.94	7667.2

Although the F-18 should spend the majority of its flight time within the regions defined by the composite mission profile, operations at and outside the corners of the flight envelope were also anticipated. Critical design points were then selected, some of which were not within the composite mission matrix of flight conditions. The total of all the mission profiles, flight envelopes, and ground operations form the F-18 operational mission profile.

F-18 Mission Environment

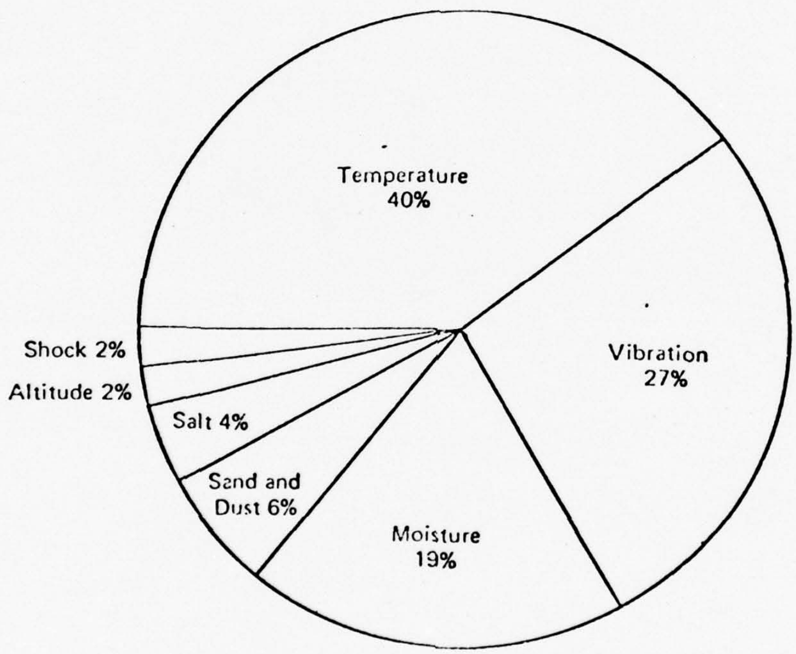
Following development of F-18 mission profiles and ground operating conditions, the design environment was established. Although the expected operational environment has many elements, several have been shown to be responsible for many equipment failures. These include:

- o Flight loads (normal acceleration)
- o Vibration, shock and acoustical noise
- o Temperature, altitude and humidity
- o Salt, sand and dust (8:7).

Studies have indicated that three of these factors - temperature, vibration and moisture - account for a majority of environmentally-induced aircraft equipment failures. The results of one study of avionics equipment presented in Figure 4 (4:45) indicates that 86 percent of these failures were attributable to temperature, vibration and moisture. Accordingly, these environments were stressed in the development of the F-18 OME (8:7). The other elements, although producing relatively less impact on field failures, are significant and were also considered. Hydro-mechanical equipment is expected to generally follow the above

failure pattern (8:7) with possible increased importance of the flight loads environment.

FIGURE 4
AVIONIC EQUIPMENT FAILURE CAUSES
Environmentally-Related Failures



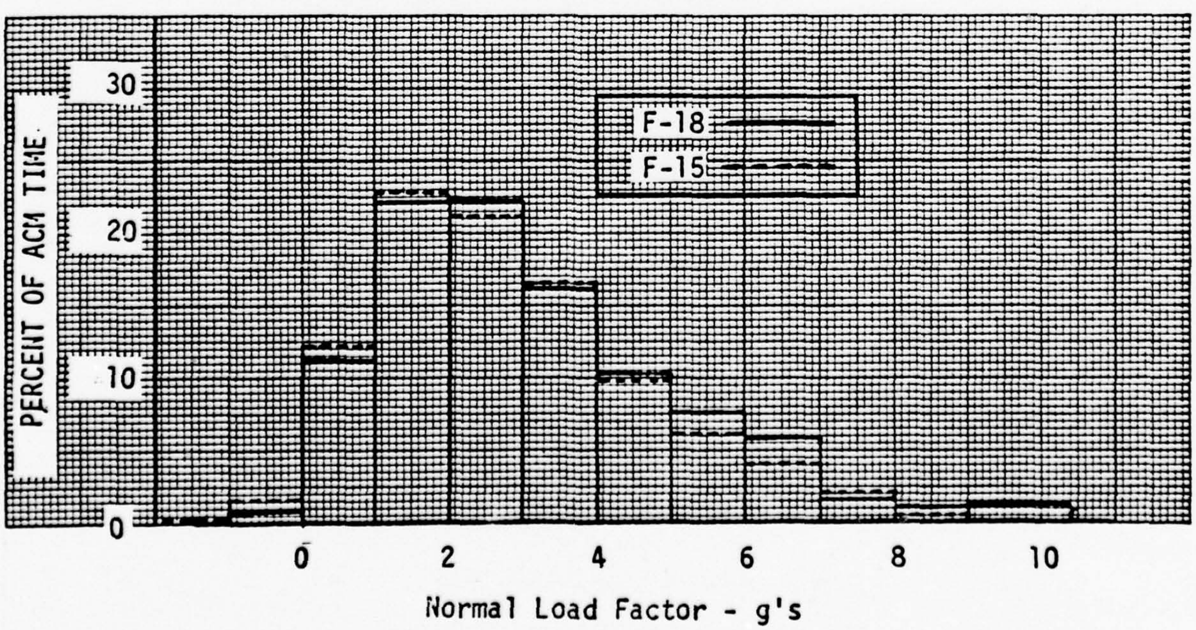
In the following sections, selected environmental elements are briefly discussed in relation to F-18 design requirements.

Flight Load Environment.

The most dynamic portion of the composite mission is the Air Combat Maneuvering (ACM) phase of the combat mission segment. ACM comprises 3.34 minutes of the 8.11 minute combat segment, and represents approximately

3 percent of the mission flight time. However, the environmental extremes encountered in this phase are significant. Manned air combat studies utilizing the F-18 and F-15 flight simulators, and F-4, F-15 and YF-17 actual flight experience were performed to develop the expected F-18 normal load factor environment. These data are shown in Figure 5, and indicate that during ACM the airplane will likely be stressed beyond its normal design load factor for a small portion of an engagement (9:15). Approximately 2.5 percent of the F-18 ACM time is expected to be above the 7.5 "g" design limit load factor. Flight loads for other mission segments and critical mission points were similarly derived to establish equipment design criteria.

FIGURE 5
DISTRIBUTION OF NORMAL LOAD FACTOR DURING
AIR COMBAT MANEUVERING



Thermal Environment.

The thermal environment for aircraft equipment depends on external factors such as ambient temperature, humidity, altitude and Mach, plus internal factors such as equipment heat dissipation and aircraft-supplied cooling air. Study of the external thermal influences on F-18 equipment environment included:

- o Climatology studies of proposed land-based and open ocean operations areas
- o Temperature distributions at sea level and altitude for standard, hot, cold and tropical conditions
- o Mission segments environment conditions such as Mach and altitude, plus frequency and time per occurrence
- o Extreme transient maneuvers and the rapid temperature, pressure and humidity changes which result (9-24).

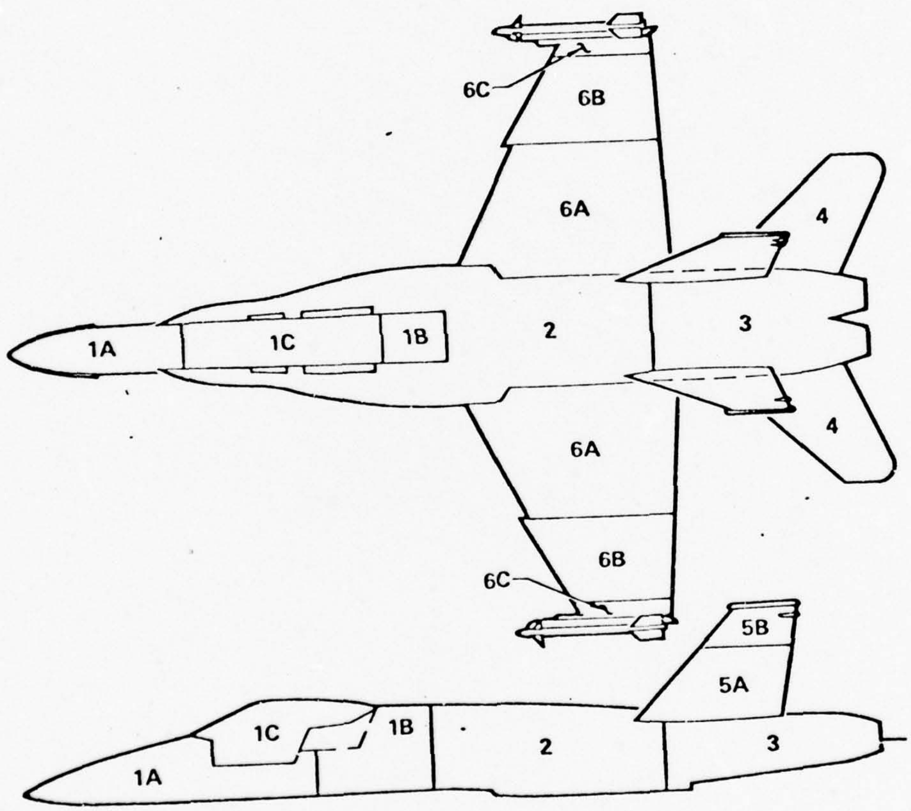
To consider internal thermal influences,the airplane was divided into 11 thermal zones and design requirements in each zone were established (10:15).

Vibration Environment.

Vibration is a dynamic-related environment which has a significant effect on equipment reliability. F-18 vibration design criteria were based on past experience of vibration measurements of other fighters including the YF-17 prototype, and prediction of the specific F-18 environment based on the mission profiles. Vibration levels were established for equipment located in separate zones of the airplane, divided as shown in Figure 6 (8:9). In developing this environment,

considerations included critical flight phases such as catapult and arrested landings, high-speed low-altitude flight in turbulent air, ACM and gunfirings, as well as normal flight operations.

FIGURE 6
AIRCRAFT ZONES
Vibration Typical



Ground Environment.

During the F-18 life cycle, less than 4 percent of the total time will be in flight (9:20). The remainder will be in storage, handling, maintenance, servicing and turnaround in a land-based or carrier deck

environment. The large amount of time and the associated environments have been considered in the F-18 systems design. The non-operational ground environment considers seawater spray, stack gas from non-nuclear powered aircraft carriers, rain, abrasion from non-skid flight deck covering, humidity, exhaust fumes and deposits from other aircraft, electromagnetic interference, airborne contaminants and temperature. Additionally, operational ground activities such as taxi, refueling, arming, inspections and maintenance were considered in the overall design requirements for equipment.

Integrated Test Program

The F-18 integrated test program is structured to develop and prove the design, and later to ensure that equipment is produced according to the proven design (11:2). The program establishes a logical sequence of testing at increasing levels of assembly and environmental complexity, and describes the feedback of test results into the design process to produce high reliability equipment. The test phase is divided into three major categories - development, demonstration and acceptance (8:14). The objective of the development phase is early design assessment at mission critical environments. This includes performance and environmental testing, and a Test, Analyze and Fix (TAAF) reliability growth program with closed loop failure reporting. The objective of the demonstration phase is verification of design requirements during laboratory and actual flight conditions. Included in this program are 50 dedicated reliability demonstration flights (8:16). During the acceptance phase,

tests will be conducted on equipment to be delivered for production usage to verify that the equipment was built and performs to the approved design configuration.

An accelerated testing approach is planned to time compress the actual design life into a reduced test time to stay within realistic test span times and funding limits (8:14). For certain critical mission equipment such as the radar, combined temperature and vibration environmental cycling will be accomplished (18). Modifications to existing test chambers will be required for conduct of these tests. Testing should be more effective in inducing failures, and the additional costs of chamber modifications should be partially offset by reduced chamber time. Specified reliability development testing requirements for equipment will be included in particular equipment specifications. This will allow tailoring of the MIL-STD-781B test environments to that actually developed from the F-18 OME. A summary of technical changes for OME testing of typical avionics equipment is shown in Figure 7 (12).

FIGURE 7

AVIONICS EQUIPMENT

SUMMARY OF TECHNICAL CHANGES FOR OME

	BASELINE	OME
(1) RELIABILITY DEVELOPMENT		
TEST TIME	4700 → 6000	4400
TEMP EXTREMES		
o CHAMBER	-65°F TO 160°F	-65°F TO 185°F
o COOLING AIR	-65°F TO 120°F	-65°F TO 145°F
TEMP SHOCK		
o CHAMBER	°F/MIN	°F/MIN
o COOLING AIR	°F/MIN	°F/MIN
o NUMBER OF CYCLES	1200 → 1600	1920
VIBRATION		
o TYPE	FIXED SINE	RANDOM
o INTENSITY	$\pm 2.2g$	MAX PERFORMANCE
o DURATION	10 MIN/HR	ACC. LIFE
HUMIDITY	N/A	PER MISSION
ALTITUDE	N/A	$0\text{-}50^{K}$ FT
(2) QUAL TESTING		
TEMP/ALT	MIL-T-5422 WITH MOD FOR F-18	o ADDS HUMIDITY o INCREASES TEST TIME BY X 2
SALT/FOG	MIL-T-5422 48 HR	96 HR TEST

(3) OME SUMMARY OF ESTIMATED BENEFITS

- TEMP/ALT TEST INCREASES FROM 75 HR TO 3600 HR
- HUMIDITY ON 3 VS 1 UNIT
- COMBINED TEMP/ALT/HUMIDITY
- VIBRATION AND TEMP ALT ON 3 VS 2 UNITS
- ESTIMATED 2 → 5 TIMES MORE FAILURES
- TEMP/SHOCK

SECTION III

RELIABILITY IMPLICATIONS

General

The key factor in the success of the F-18 will be attainment of reliability significantly higher than current fleet aircraft such as the F-4J and A-7E. As mission requirements become more varied and sophisticated to keep pace with the changing threat, weapon systems tend to become more complex to satisfy increased performance requirements. Thus reliability becomes more difficult to define and achieve as a design parameter, to demonstrate in development and control in production, and to assure as an operational characteristic during fleet use. These difficulties can be minimized by the exercise of very deliberate and positive reliability engineering methods throughout the systems life cycle (19:2). Realizing this challenge, the Naval Air Systems Command has developed a "New Look" management approach to assure the acquisition of effective and reliable systems. Figure 8 summarizes this approach to increasing combat effectiveness. All of these management concepts can be found in use in the F-18 program. This program is the Command's first dedicated effort of designing reliability into an aircraft.

The "New Look" approach to F-18 design starts with the use of expected operational and environmental conditions derived from realistic mission profiles in order to tailor existing specifications and test. Design features based on the OME are combined with a high reliability parts program and a planned stringent test effort to help ensure maximum reliability (1). F-18 reliability improvement due to OME design attention

FIGURE 8

MATERIAL ACQUISITION FUNDAMENTALS

- OBJECTIVES
  - IMPROVE FLEET READINESS
  - ENHANCE MATERIAL ACQUISITION EFFICIENCY

- CORNERSTONES
  - MAXIMIZE RELIABILITY/MAINTAINABILITY
  - OPTIMIZE QUALITY ASSURANCE
  - MINIMIZE LIFE CYCLE COST

- R&M
  - MISSION PROFILE DEFINITION
  - STRESS ANALYSIS
  - DERATING CRITERIA
  - WORST CASE ANALYSIS
  - SNEAK CIRCUIT ANALYSIS
  - PREDICTION/ALLOCATIONS
  - FAILURE MODES & EFFECTS ANALYSIS
  - TEST, ANALYZE, & FIX WITH CLOSED LOOP REPORTING
  - DESIGN REVIEWS
  - MISSION PROFILE QUALIFICATION TEST

- Q.A.
  - PROCESS CONTROL ATTAINMENT/MAINTAINABILITY
  - MISSION PROFILE ACCEPTANCE TEST

- COST
  - DESIGN TO COST

and testing has been estimated by the contractor and is presented in Figure 9 (12). Significant improvement in expected fleet reliability should help to reduce the current trend of less-than-desired operational readiness of new weapon systems in the fleet.

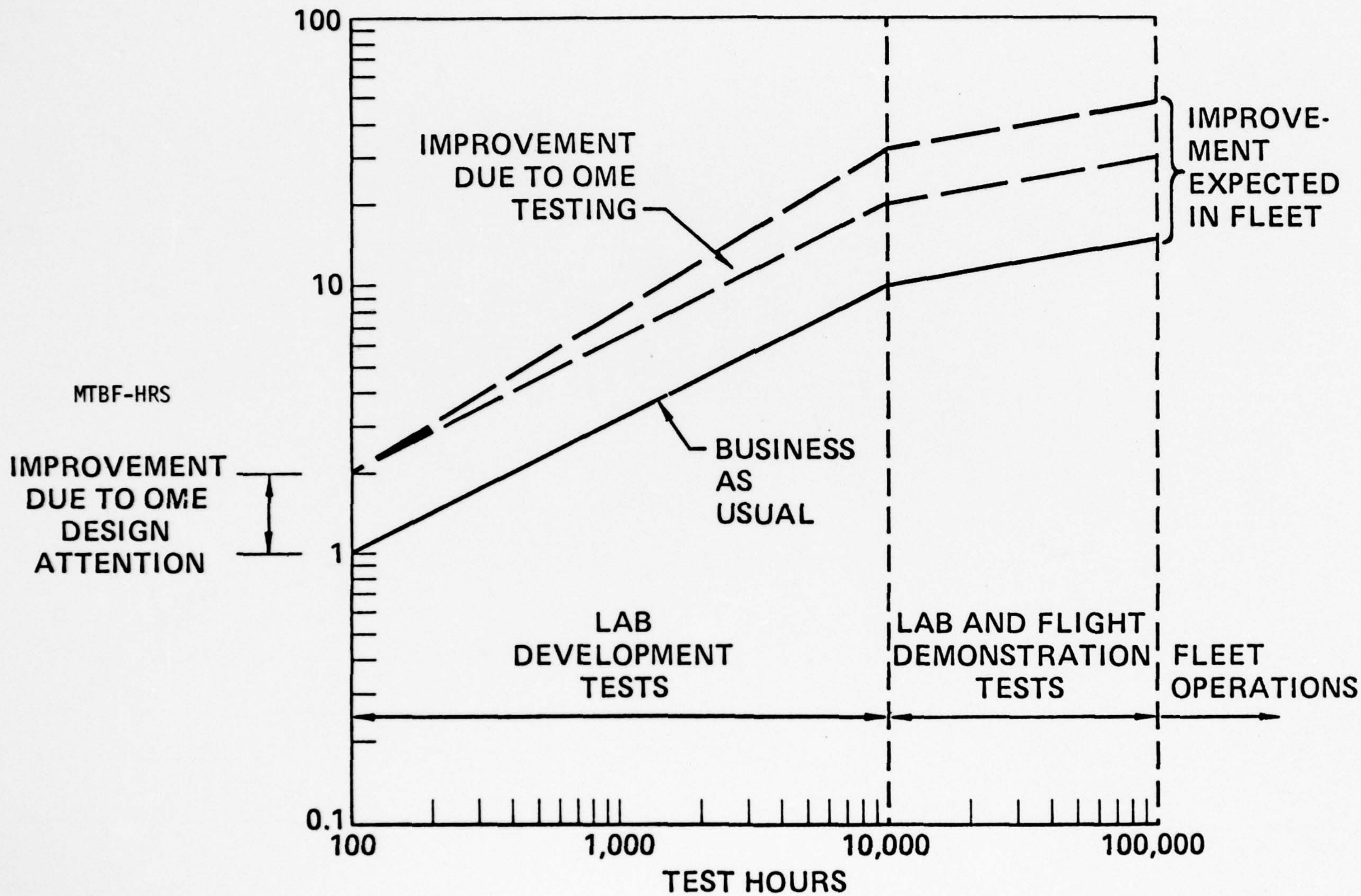
F-18 Contract Requirements

The prime contract for the F-18 and the engine development contract contain firm guarantees for reliability and maintainability. The contractors have set design goals for reliability and maintainability which provide a margin over their contract guarantees. The goals are, in turn, being allocated to the subsystem and component design tasks. As the design develops, predictions of equipment reliability are being compared with the allocation to determine acceptability.

At key decision points during the Full Scale Development phase, the contractor is required to demonstrate reliability growth consistent with meeting the guarantees. At 1200 cumulative flight hours, which corresponds to the low rate production decision approximately 18 months after first flight, the system mean flight hours between failures (MFHBF) must be 2.9 hours or greater. At 2500 flight hours, which corresponds to full-production decision approximately 29 months after first flight, the system MFHBF must exceed 3.7 hours (15). At maturity, the F-18 design MFHBF exceeds 5 hours as compared with existing MFHBF's for the F-4J of 0.6 hours and A-7E of 1.2 hours.

Reliability, maintainability, program milestones and other life cycle cost factors have been incentivized in the F-18 contract by implementation of an award payment plan. The reliability and maintainability factors are measured at selected points during the Full Scale Development phase and the

FIGURE 9
TYPICAL F-18 EQUIPMENT RELIABILITY GROWTH
DESIGN AND TEST WITH "NEW LOOK" AND OME



potential award payments are used to incentivize the contractor to achieve reliability and maintainability early in the development cycle. The contractor's ability to earn award payments is based solely on his ability to achieve and improve reliability and maintainability factors. The total fee available under the award payment plan is 39 million dollars, 24 million of which is directly related to achievement of reliability and maintainability requirements (15:108).

SECTION IV

LIFE CYCLE COST IMPLICATIONS

General

Life cycle cost (LCC) of a system is the total cost of acquisition and ownership of that system over its full life. The two primary factors included in LCC are development/acquisition costs and Operating and Support (O&S) costs. Estimates of typical weapon systems O&S costs as a percentage of LCC vary from 60 to 75 percent. The greatly increasing cost of major weapon systems coupled with a fixed or diminishing defense budget, in terms of constant year dollars, has forced the Department of Defense (DOD) to consider its total commitment when acquiring new systems (3:11). The DOD and the Navy recognize that a decision to procure a new system is also a decision to acquire and maintain support for the system. Because O&S resource requirements are driven by the design of system equipment (reliability, maintainability and unit production cost), it is critical that LCC be considered early in any development cycle (6:71). It is extremely difficult and costly to reduce O&S costs once the design is complete or the system is deployed.

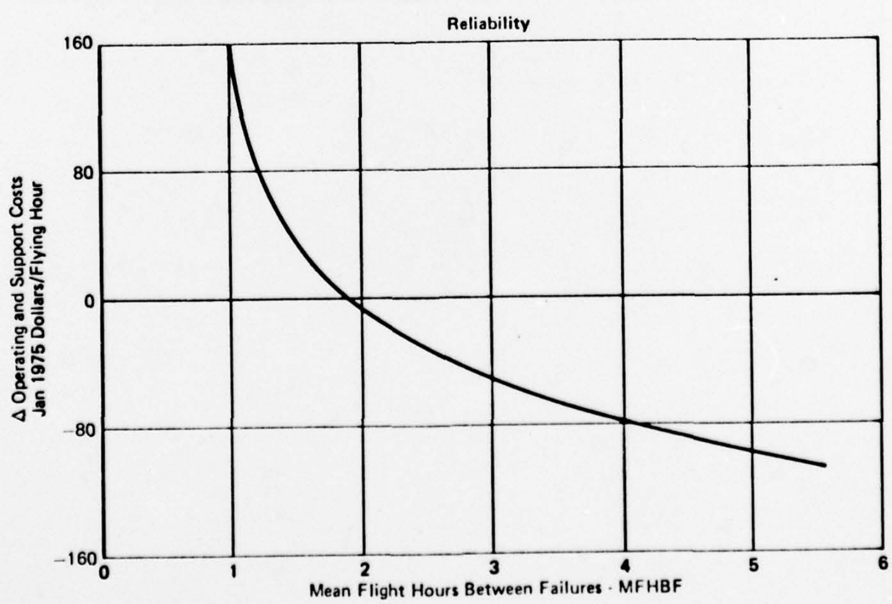
F-18 Life Cycle Costs

The Navy has carefully predicted and analyzed F-18 O&S costs early in the development phase, thus offering the greatest potential for savings (14:II-2). Attainment of guaranteed reliability and maintainability objectives should result in a 20 to 30 percent reduction in manpower required to support the F-18 as compared to the A-7E (14:V-1).

This in itself will greatly reduce LCC and help to alleviate crowded working and living conditions aboard aircraft carriers. The contractor's attainment of program milestones and other LCC factors are incentivized through the potential award of a maximum of 15 million dollars spread over ten semi-annual payments (15:108). LCC factors that are incentivized include the contractor's ability to identify design-to-cost/LCC tradeoffs, control of pertinent LCC parameters resulting from subcontractor's and supplier's efforts, acceptability of the Logistic Support Analysis and the reduction of personnel skill levels required to maintain the airplane.

A major factor in reducing O&S costs and total LCC is improved reliability of F-18 equipment. The results of an analysis of reliability sensitivity of the F-18 O&S cost model is presented in Figure 10 (15:IC-3).

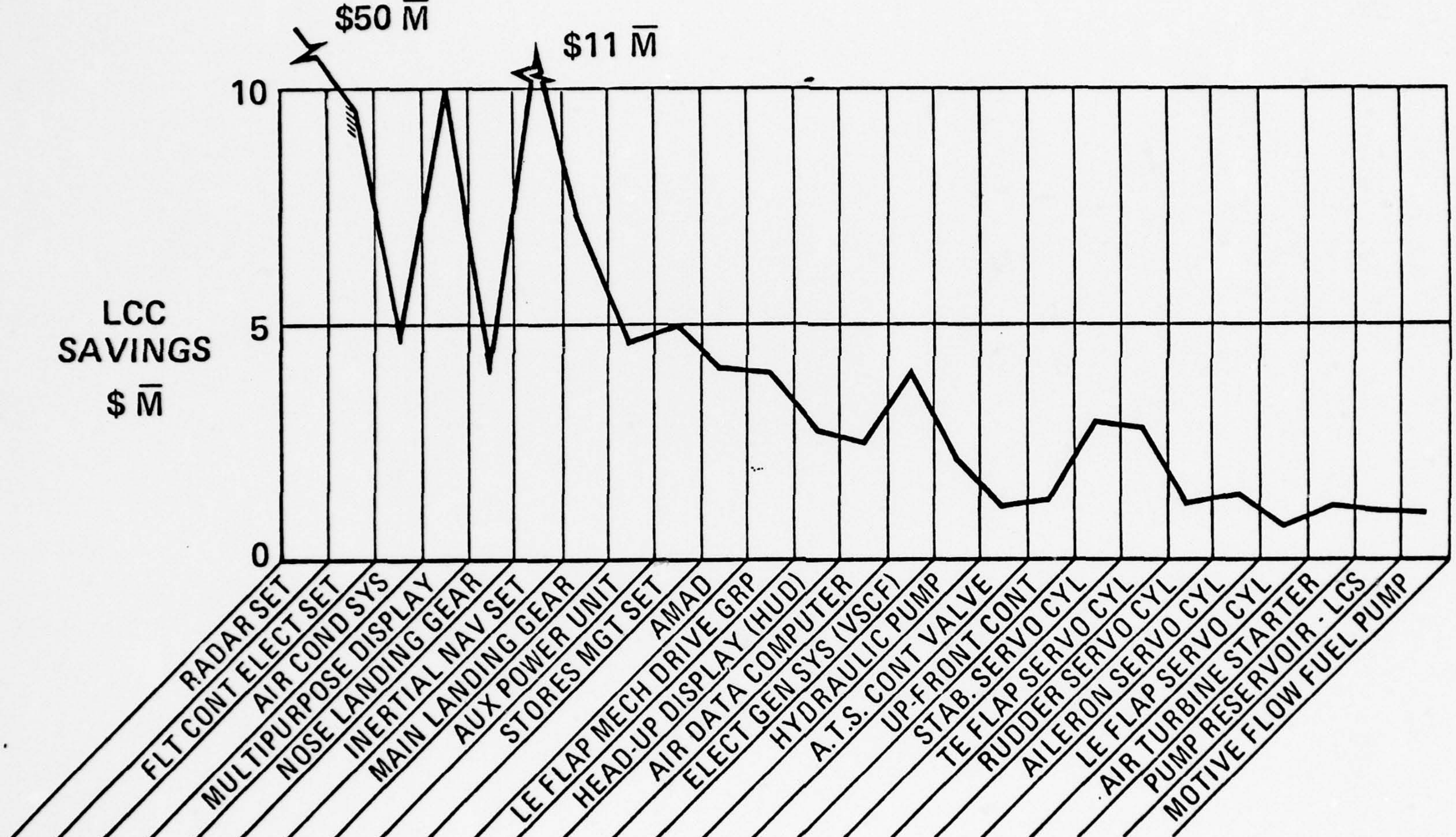
FIGURE 10 - SENSIVITY OF F-18 O&S COSTS TO RELIABILITY



It has been shown earlier in this study that a key element in achieving increased reliability of the F-18 in the fleet is the use of the expected operational mission environment as the basis for design and test requirements. The potential LCC savings for selecting the OME option of design and test requirements is shown in Figure 11 for selected equipments (12). The additional cost of OME design and test must be borne by the F-18 Program Office. Therefore, tradeoffs between design-to-cost goals and Life Cycle Costs must be made with respect to the program's funding profile. Criteria used by the F-18 Program Manager in selecting equipment for full OME design and test requirements include equipment relationship to mission success, safety of flight considerations, new state-of-the-art technology and cost/benefit analysis (5). It is also possible that the contractor will exercise the option of OME testing on selected items if tradeoff analysis indicates attainment of possible award fees exceeds the additional cost involved, or if meeting reliability guarantees appears marginal. To date, the Navy has selected 13 items for OME design and testing requirements, many more are still under evaluation. The items selected include:

- radar set
- flight control electronics set
- inerital navigation system (INS)
- multi-purpose display
- air-conditioning system
- auxiliary power unit (APU)
- airplane mounted accessory drive (AMAD)
- pilot's heads-up display (HUD)
- motive flow fuel pump
- hydraulic reservoir assembly
- maintenance monitor panel
- air turbine starter control valve
- up-front control unit

FIGURE 11
OME LIFE CYCLE COST SAVINGS



The total added cost to the Navy of OME design and test of these items is approximately 3 million dollars; the expected life cycle cost savings is estimated to be 100.2 million dollars -- over a 30:1 payback. The LCC savings are significant and demonstrate the effectiveness of the Naval Air Systems Command's "New Look" approach to management of material acquisition programs.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The operational reliability of many weapon systems in the fleet is far below that which was specified in requirement documents, or demonstrated during development testing. Long-standing design and test requirements and philosophies have not succeeded in providing needed levels of operational readiness nor in constraining life cycle cost growth. The trend toward decreases in combat effectiveness over what was originally planned, and rising costs to support unreliable systems must be reversed to allow the Navy to effectively meet the current and projected threat scenario, and derive maximum benefit from each scarce dollar it receives. In the F-18 program, the contractor is utilizing realistic mission profiles to establish the expected operational environment of the airplane. This environment has been provided to the designers of systems and equipment, and will be utilized during the testing and demonstration phases to ensure specifications and reliability requirements have been met. The results of more realistic design and test efforts should lead to significant improvements in fleet reliability of the F-18, and also serve to reduce operational and support costs in future years. The F-18 program's implementation of the operational mission environment concept early in the design phase appears to be a very sound and innovative approach with great potential for increasing system operational effectiveness.

Recommendations

To improve operational reliability of planned systems, accurate knowledge of the expected operational environment of that system is required. Operational mission profiles should be developed as the first step in definition of the expected environment a system will be exposed to. This information is an essential input to the development of design and test requirements to ensure reliable and cost-effective systems in the fleet. The requirement for, and standard methodology of developing mission profiles should be a high priority task of DOD managers. A comprehensive review and evaluation of all systems and equipment utilizing mission profiles during the early development phase should be conducted as the initial step in this process. The results of this study should be compared with the test levels in existing Military Standards and Specifications, and recommended changes to test profiles should be established. Additionally, the F-18 Naval Strike Fighter and other systems developed with the aid of mission profiles should be tracked through service introduction and subsequent operating life to verify actual reliability and O&S costs as compared to planned and to similar systems acquired without the use of this concept.

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